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COMMENTS OF GENERAL ELECTRIC COMPANY ON

PHASE 2 REPORT - REVIEW COPY
FURTHER SITE CHARACTERIZATION AND ANALYSIS
VOLUME 2B - PRELIMINARY MODEL CALIBRATION REPORT
HUDSON RIVER PCBs REASSESSMENT RI/FS
OCTOBER 1996

November 21, 1996

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EXECUTIVE SUMMARY

General Electric Company ("GE") submits these comments on the United States Environmental Protection Agency's ("EPA") "Phase 2 Report - Review Copy, Further Site Characterization and Analysis, Volume 2B - Preliminary Model Calibration Report, Hudson River PCBs Reassessment RI/FS" (October 1996) ("Report"). The Report describes the current status of EPA's modeling effort to predict the levels of PCBs in sediment, water and fish in the Upper Hudson River under various remedial scenarios, including no action.

It appears that GE and EPA agree on several important aspects of the modeling effort for the Hudson River PCBs Superfund Site. We agree generally with the objectives and focus of the modeling effort identified in the Report, as well as the Agency's conclusion that modeling is the appropriate way to address the questions of PCB fate, transport and bioaccumulation in the Upper Hudson. We also agree with EPA that the principle of "mass balance" should be the basis of its models and on the need to assure that model predictions are calibrated against and are consistent with the available data.

Notwithstanding this general agreement, there are several fundamental problems with EPA's models that should be corrected as EPA moves forward. We urge EPA to correct these problems and look forward to assisting the Agency in this endeavor. Given that the modeling effort is a "work in progress," we request that the Agency provide an opportunity to comment on its work in refining the models before they are used to make predictions about the appropriateness of remedial action. The problems that EPA must address as it develops its model more fully are set out in detail in these comments and are summarized below:

1. There are three significant problems with the solids balance in EPA's fate and transport model. EPA has underestimated the solids loadings to the Upper River from the Snook and Moses Kills. EPA's deposition and resuspension rates, particularly during low flow, are too high and cannot be calibrated against the other solids parameters. Finally, the sedimentation rate is not integrated into the model as the net of deposition and resuspension, violating the principle of mass balance.

2. The problems with the solids mass balance affect EPA's estimates of the PCB mass balance. By overestimating resuspension and deposition, underestimating tributary solids loadings, and decoupling sedimentation from the other solids parameters, the model overstates the transfer of PCBs from sediment to water, which, in turn, implies greater benefits from remedial actions aimed at sediments than will be the true case.

3. GE has several other concerns with the PCB mass balance in EPA's model. The model's estimate of initial conditions of PCBs in the sediment are based on data that do not reflect the significant loadings of sediments and PCBs from the Allen Mill in 1991 to 1993. EPA's model also fails to consider the effect of PCB dechlorination in the sediments of the Upper Hudson. The manner in which EPA "corrected" GE's PCB data also appears to contain errors.

Finally, the limited time period for which EPA has attempted to calibrate the model is insufficient to test the model's ability to represent the long-term fate of sediment PCBs.

4. EPA's model is unable to achieve a PCB mass balance across the Thompson Island Pool ("TIP") without resort to hypothesized mechanisms, particularly the introduction of groundwater flux of buried PCBs, for which there is no factual demonstration. There are other plausible hypothesized mechanisms that can explain the mass imbalance of PCBs across the TIP, including (1) inaccurate estimation of the PCB load across the TIP by GE's monitoring program, (2) increased surface sediment concentrations resulting from the Allen Mill release, (3) external load from dredge spoil sites, or (4) resuspension of surface sediments at low flows. Until the cause of the mass imbalance of PCBs across the TIP is understood, model predictions of remedial scenarios will not be sufficiently fact-based to be useful in addressing the key reassessment questions. GE is working to collect data to test all these hypotheses and will provide these data to EPA as they become available.

5. The shortcomings in EPA's preliminary fate and transport model will become more apparent as EPA attempts to calibrate it against the historical PCB data in fish, water and sediments. For example, EPA's proposed groundwater inflow would result in greater quantities of PCBs moving into the water column from sediments than the historical water monitoring data show. Similarly, this mechanism would result in depletion of the PCB inventory at a rate that is much higher than the sediment data show.

6. EPA should not use the two steady-state statistically-based bioaccumulation models -- the Bivariate Statistical Model and the Probabilistic Food Chain Model -- to make predictions because they ignore the short and long-term variability in the relationships among PCB levels in the water column, sediment and fish and do not attempt to describe or respond to the mechanisms by which fish bioaccumulate PCBs. Instead, EPA should use a time-variable, mechanistic food web model, such as the Gobas model, which explicitly incorporates variability in exposure, uptake and depuration of PCBs in fish and reflects real world bioenergetic and toxicokinetic mechanisms. GE has been developing such a model and offers to share this work with EPA as the Agency develops its food web model.

7. EPA's depth of scour model to predict the effect of a 100 year flood on solids and PCBs in the Upper Hudson River is sound in its application of principles and its analytic approach. The model properly applies the Lick equations to the dynamics of cohesive sediment resuspension, but we believe there are some errors in the application of these equations. In addition, we recommend that EPA use a modified van Rijn model to model the resuspension properties of non-cohesive sediments in the Upper Hudson.

8. EPA must test its models against the extensive data set for the Upper Hudson River to have any confidence in their predictive powers. Specifically, EPA should validate its:

- Solids balance model against (1) spatial patterns of TSS during low flow, (2) temporal and spatial patterns of TSS and water column PCBs during flood events, and (3) annual average solids loading passing Schuylerville, Stillwater and Waterford.

- PCB fate model against (1) spatial patterns of water column PCBs during low flow and (2) spatial changes in water column PCB composition.
- Estimate of PCB loss against long-term changes in surface sediment PCB levels, vertical profiles of PCBs in sediments, and PCB inventory in sediment.
- Fate and transport model against the annual average flux of PCBs passing Schuylerville, Stillwater and Waterford.
- Estimate of the effect of the Allen Mill release against the apparent increase in the PCB flux from Fort Edward to Thompson Island Dam/Schuylerville that occurred between the mid- to late-1980s and the 1990s.
- Bioaccumulation models against temporal changes in predatory and forage fish at the TIP and Stillwater over a 15-year period and the response of the fish to the short-term changes in water column PCB levels in the early 1990s.

9. EPA has not clearly defined its objectives in using the Thomann model of PCB fate, transport and bioaccumulation in the Lower Hudson River. Given the present scope of the reassessment, EPA should only use this model to assess whether remediation in the Upper River would have an unacceptable adverse impact on the Lower River, and only after Thomann and Farley have completed their update of the model.

GE commends EPA for providing this opportunity to comment on its modeling effort. As EPA recognizes, some of the topics in the Report are closely related to EPA's yet-to-be-issued Data Evaluation Report. As a result, we may revisit some of these topics as they are developed more fully in future reports.

I. INTRODUCTION

In 1989, Region II of the U.S. Environmental Protection Agency ("EPA") decided to reassess its 1984 decision under the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA" or "Superfund") that no action should be taken with regard to sediments at the Hudson River PCB site (U.S. EPA, 1984). This reassessment is to determine what CERCLA action, if any, should be taken with regard to the PCB-contaminated sediments in the Upper Hudson River. The reassessment is focused on answering three central questions (U.S. EPA, 1996b; pg. 3-1):

1. When will PCB levels in fish populations recover to levels meeting human health and ecological risk criteria under continued No Action?

2. Can remedies other than No Action significantly shorten the time required to achieve acceptable risk levels?

3. Are there contaminated sediments now buried and effectively sequestered from the food chain that are likely to become "reactivated" following a major flood, possibly resulting in an increase in contamination of the fish population?

As a first step, the reassessment reviewed existing data (U.S. EPA, 1991) and collected new data. EPA has now turned to developing a fate and transport model and three associated bioaccumulation models for the Upper Hudson River to help answer these questions. In addition, the Agency has developed a separate sediment model for flood conditions and examined an existing model of PCB concentrations in striped bass in the Lower River. If successful, the modeling effort will replicate data reflecting known past conditions in the River - water flows, total suspended solids ("TSS") and PCB concentrations in water, and PCB concentrations in sediment and through the aquatic food chain up to the fish that people, birds, and other animals may eat. If successfully developed, EPA can then use the models to predict the course of natural recovery with no intrusive remedial activity, as well as the future PCB concentrations in environmental media and aquatic biota under assumed remedial scenarios. In October 1996, EPA issued for review and comment its Preliminary Model Calibration Report ("Report") (U.S. EPA, 1996b).

These comments, prepared with the aid of HydroQual, Inc. (experts in modeling the behavior of contaminants in surface water and biota) set out General Electric Company's ("GE's") views regarding the Report. As the Agency recognizes, some of the topics addressed in the Report are not fully developed, and some are intertwined with issues to be addressed in the Data Evaluation Report, which the Agency has not yet issued. Consequently, as these topics are more fully developed and discussed in future reports, GE is likely to return to many of the issues addressed in these comments.

GE generally agrees with the fundamental objectives and focus that are the foundation for the present Report. GE largely agrees with EPA on the central questions which the reassessment should address (GE believes, however, that EPA needs not only to consider what impact a large flow will have on PCB levels in the River, but also whether and to what extent remedial efforts would mitigate these impacts). GE also agrees with EPA that modeling is the appropriate methodology for addressing the questions of PCB fate, transport and bioaccumulation in the Upper Hudson River and is the appropriate way to achieve the reassessment objectives. Moreover, GE agrees with EPA that mass balance is the appropriate principle on which to base the fate and transport model.

Based upon the information provided in the Report, we believe EPA and GE also agree on the basis by which a model should be judged: (1) its congruence with accepted scientific laws and principles; (2) the internal consistency of the physical, chemical, and biological mechanisms that are reflected in the model; (3) the plausibility and reasonableness of the professional judgments and assumptions used at points where scientific principle or relevant data do not constrain the modeler; and, most important, (4) its ability to replicate observations of the physical system being modeled over appropriate time and space scales.

Modeling provides a method for describing the relationship of elements in a complex natural system, such as the Upper Hudson River. It requires the modeler to analyze and describe the relations between the elements in the system. It develops knowledge of which elements have the greatest influence over the results of interest and which elements have the greatest uncertainty associated with them. This process allows a refined focus on those areas where data collection, laboratory experiments or refinement of judgment will be of greatest value – and in some cases will be essential – to produce modeling results that will be useful for decision-making. The validation of the model against known data provides an acid test for the ultimate value of the model and defines the degree to which one's confidence in the models' predictive power is warranted.

In its present iteration, many aspects of EPA's models appear to meet the evaluation criteria set out above, but there are others where the model clearly falls short. This may be the result of the EPA's models being works in progress, and we commend EPA for seeking input during the development phase to help improve the quality of the Agency's effort. This is the spirit in which we submit these comments. Our comments address these central aspects of modeling and reflect, as well, the experience of GE and its consultants in attempting to construct GE's own PCB fate, transport and bioaccumulation model for the Upper Hudson River.

II. EPA's FATE AND TRANSPORT MODEL

EPA's fate and transport model attempts to model the mass balance of solids and PCBs in the Upper River. Four factors primarily control the calibration of this model: solids or sediment transport, PCB partitioning, upstream loading of PCBs, and initial sediment PCB conditions. Because these factors also control PCB dynamics in the river and the operation of the model, it is critical that the model accurately define them. GE and EPA have no material disagreement about PCB partitioning or what the data show as the upstream loading of PCBs (although a question remains as to the accuracy of that data, particularly after the Allen Mill discharges of 1991 to 1993). We do have clear differences of opinion on EPA's assumed initial sediment PCB conditions because the model uses 1991 sediment PCB data to reflect conditions in 1993, ignoring the large amount of PCB-containing sediment that entered the River upstream of the model boundary between September 1991 and March 1993 from the failure of the Allen Mill. This discharge probably affected surficial sediment conditions in the Thompson Island Pool ("TIP"). We also have several areas of significant disagreement with regard to solids (or sediment) transport issues and the associated behavior of PCBs. These are the central issues on which we focus our comments on EPA's fate and transport model.

A. Solids Mass Balance

The physical-chemical fate and transport model that EPA has developed for the Upper Hudson River appropriately relies on the principle of mass balance. As both EPA and GE have recognized, solids transport is critical to the fate of PCBs in the River because of the affinity of PCBs for solids, the release of PCBs to the water column through sediment resuspension, and the burial of PCBs through net solids deposition. Development of a solids mass balance model that accurately simulates the loading, resuspension, deposition and transport of suspended solids and sediments in the Upper Hudson River is thus necessary to the calibration of the PCB model and to the model's ability to evaluate remedial alternatives. Without a detailed understanding of sediment transport, the model will not accurately predict the fate and transport of PCBs in the Upper Hudson River and thus will not materially assist EPA in its evaluation of alternatives.

The solids mass balance described in the Report has several significant shortcomings:

1. Solids loading to the River from Snook Kill and Moses Kill are underestimated;
2. Deposition and resuspension rates, particularly during low flow, are too high; and
3. The sedimentation rate is not integrated into the model as the net of deposition and resuspension, violating the principle of mass balance.

The solids mass balance is constrained by data on TSS concentrations and mass flux in the water column at various points in the River. From reach to reach, the TSS levels are controlled by solids loading from upstream and tributaries and by the sedimentation rate. The sedimentation rate, in turn, is the net difference between solids deposition and solids resuspension. Thus, solids loading, deposition and resuspension, and sedimentation rate are all closely related in achieving the solids mass balance.

There also is an important link between the solids and PCB mass balances. Changes in the internal working of the solids mass balance model can have major impacts on the PCB mass balance. The PCB mass balance provides a check on the solids mass balance and *vice versa*. The effect of changes made in one aspect of the model must be considered in evaluating both aspects of the model. Consequently, many of the issues that arise in examining the solids balance estimates also arise in the context of the PCB mass balance estimates.

Solids Loading from the Tributaries

EPA has underestimated solids loadings from tributaries to the Upper Hudson River. Although EPA uses the proper approach for estimating loads from the upstream and major tributary sources, the method used to estimate solids loads from minor tributaries, particularly into the TIP, results in a significant underestimation of actual loadings. This is confirmed by data that EPA collected in 1994 and reported in the Database Report (U.S. EPA, 1995), but which EPA has not yet incorporated into its model.

The standard and accepted method for estimating solids loading is to use available TSS and flow rate data to develop a solids rating curve, which can then be used to predict solids loading as a function of flow rate. This is the method EPA used to develop solids loadings relationships for the Upper Hudson River at Fort Edward (the upstream boundary), the Hoosic River, and the Mohawk River, and GE generally agrees with EPA's approach with respect to the loadings estimates for these sources. GE also agrees with EPA's use of the minimum variance unbiased estimator ("MVUE") to correct for log-linear regression analysis bias during development of the solids rating curve because this will provide increased accuracy in estimating solids loads.

Nevertheless, we believe that further analysis of the larger data set will improve the accuracy of these loadings estimates. First, with respect to the loadings estimate at Fort Edward, EPA should include all the available TSS data in the MVUE analysis. By relying only on the limited EPA Phase 2 1993 TSS data set, the validity of EPA's analysis is uncertain. EPA rejected both the earlier TSS data, claiming that the TSS-flow relationship had changed over time, and the TSS data GE collected in 1993, but the Agency failed to conduct a proper statistical analysis to ensure that it was appropriate to exclude these data. We are confident that such an analysis would show that EPA should include a large portion of the data set in the TSS-flow relationship, which will increase the power and accuracy of the regression. Second, EPA should validate its loadings estimates for all the tributaries and the upstream boundary with data collected in April, 1994 and other high flow periods. This validation is important to determine whether EPA's solids loadings estimates are correct.

EPA correctly recognized that Batten Kill and Fish Creek contribute significant solids loads to the Upper Hudson River (U.S. EPA, 1996b; pg. 4-7). The Agency estimated the loadings from these tributaries by comparing them to and developing a ratio of the TSS-flow relationship developed for the Hoosic River. This is not an unreasonable first approximation, but EPA should test the validity of the approach by comparing predicted with observed loads in the Batten Kill during April, 1994.

EPA's method for estimating TSS loads for Snook Kill and Moses Kill, on the other hand, is fundamentally flawed. EPA improperly assumed a constant TSS value of 5 mg/l for these tributaries, ignoring the evidence that they contribute substantial solids. EPA should use the data from April, 1994 to establish the relationship of solids loading from these tributaries to loadings in the Hoosic River, similar to the approach used to estimate loadings from Batten Kill and Fish Creek. Although these data are limited, they do show that these tributaries can contribute significant loadings into the TIP, with peak values of over 200 mg/l.

EPA's assumed loadings value for the Snook and Moses Kills results in an implausible loading per unit drainage area (i.e., sediment yield) for these tributaries. During the 1993 calibration period, EPA's assumed rate results in a sediment yield of 1.1 metric tons/mi^2 for the Snook and Moses Kills, 100 times less than the calculated yield of 111 metric tons/mi^2 for the Hoosic River. This vast discrepancy cannot be accounted for simply by differences in soil type and land use along the Snook and Moses Kills and the Hoosic River and thus demonstrates the invalidity of the 5 mg/l assumption for the Snook and Moses Kills.

Solids Deposition and Resuspension

The formulations that EPA presently uses to simulate deposition and resuspension in the solids transport model are unsupported by generally accepted theory and will not produce accurate predictions of solids or PCB fluxes across the sediment-water interface. EPA must include resuspension and deposition formulations that are physically consistent with the observed behavior of sediments in both laboratory and field studies in its modeling framework before it uses the solids transport model to make predictions.

There are four fundamental problems with EPA's simulation of resuspension and deposition: (1) resuspension during low flows; (2) constant resuspension rate at high flow; (3) constant settling velocity; and (4) assumed resuspension rates based on judgment and not calibrated with supporting data. These invalid assumptions result in a model that overestimates resuspension of solids and PCB movement from the sediment bed into the water column.

First, laboratory and field studies on cohesive and non-cohesive sediment erosion properties show that resuspension only occurs when the bed shear stress exceeds some critical value, which depends upon the bed properties (Galiani, et al., 1991; Hawley, 1991; Hayter and Mehta, 1986; Parchure and Mehta, 1985; van Rijn, 1984; Araturai and Krone, 1976). Examination of bottom shear stresses predicted by a two-dimensional hydrodynamic model of the Upper Hudson River that GE is developing indicates that critical shear stresses are not exceeded at typical low flow rates. As a result, resuspension will be negligible in both cohesive and non-cohesive bed areas during low flows in the Upper Hudson River. This conclusion is supported by modeling results, using calibrated and validated sediment transport models, in other riverine systems (Ziegler and Nisbet, 1994).

Second, use of a constant resuspension rate during high flows ignores the observed phenomenon of sediment bed armoring for both cohesive and non-cohesive sediments. Rather than continual resuspension at high flow, resuspension occurs only until the surface is depleted of resuspendable particles, leaving larger or cohesive particles at the surface that form an armoring layer for the particles below (Ziegler and Nisbet, 1994; Karim and Holly, 1986; van Niekerk, et al.). The assumption of a constant resuspension rate is also inconsistent with the resuspension formulation used in EPA's depth of scour model, which accounts for bed armoring of cohesive sediments. Neglecting bed armoring causes the fate and transport model to overestimate the resuspension of solids and PCBs during high flow events.

Third, EPA has assumed a constant settling velocity of 2 m/day to describe deposition rates in the Upper Hudson River. This assumption, however, does not accurately represent the dynamics of sediment deposition in the River. Laboratory studies on cohesive and non-cohesive sediments show that deposition rates vary with particle size and shear stress at the sediment-water interface, both of which change with river flow (Ziegler and Nisbet, 1994; van Rijn, 1984; Mehta and Partheniades, 1975). EPA should include these effects in the formulations used to simulate deposition in the solids transport model.

Fourth, specifying deposition and resuspension rates based on judgment and model calibration, without supporting data, can produce highly inaccurate solids fluxes between the water column and sediment. The accuracy of the flux rates is dependent on the accuracy of the solids loading estimates used in the solids mass balance. If tributary solids loadings are underestimated, as we demonstrated earlier for the TIP, the model will overestimate net resuspension in order to account for observed TSS levels.

This is illustrated by examination of the solids balance presented in the Report (U.S. EPA, 1996b; Figure 4-35). Net erosion of 9,100 MT is calculated during the simulation period. However, if Snook and Moses Kills have solids yields similar to the Hoosic River, as we believe they do, the solids loading would increase by about 22,000 MT. Instead of net erosion, the mass balance would indicate net deposition of about 13,000 MT.

The flawed deposition and resuspension rates used in the model are evident in EPA's attempts to calibrate the model. Only the <u>net</u> result of deposition and resuspension, and not the <u>absolute</u> values of deposition and resuspension, affect the water column solids balance. Thus, in the absence of an independent assessment of deposition or resuspension, efforts at calibration are circular: one parameter is played off against the other. For example, the Fort Edward to Stillwater solids balance during the low flow or "Non-Event" portion of the model calibration includes resuspension and settling fluxes that exceed the solids flux passing Stillwater (11,000 to 15,000 MT versus 10,000 MT). Because the presumed solids loading to the River between Fort Edward and Stillwater during this period approximately equaled the solids flux passing Stillwater, even eliminating deposition and resuspension would not appreciably affect the solids calibration. Thus, the solids balance provides no basis for calibration of these processes.

In contrast, the PCB calibration is very sensitive to the absolute values of deposition and resuspension and does provide a basis for calibration of the solids balance. The comparisons of model and data in Figure 4-32 of the Report show that the model overestimates water column PCBs at low PCB concentrations. This demonstrates that the model overestimates the transfer of PCBs to the water column and, hence, the solids fluxes between the sediment and water column at low flow.

Sedimentation Rate

Another fundamental problem with the solids modeling framework is that the model defines the sedimentation rate independently of the net transport of solids across the sediment-water interface. The model assumes an external net sedimentation rate of 0.22 cm/yr, derived solely from profession judgement (U.S. EPA, 1996b). This rate is unrelated to the resuspension and deposition rates used in the model. Because sedimentation is tied directly to the net transport of solids across the sediment-water interface, EPA should restructure the model to calculate the sedimentation rate as the net difference between resuspension and deposition. This will bring greater internal consistency to the model.

The result of EPA's approach is that the solids transport model predicts net erosion during the calibration period. Although net erosion might be plausible for a short time period, it is inconsistent with data showing net sedimentation in the Upper Hudson River (HydroQual, 1995a). The model's prediction of net erosion also demonstrates that EPA has underestimated the solids loadings to the River.

B. Calibration of PCB Mass Balance

GE has a number of concerns with respect to the calibration of PCBs in EPA's model. First, the problems with the solids balance – namely, the underestimation of tributary loadings, the overstatement of the resuspension and deposition rates, and the decoupling of the sedimentation rate from the other solids parameters – cause the model to overstate the transfer of PCBs from sediments to water. Second, the initial conditions of PCBs in sediment are based on data that do not reflect the significant loadings of sediments and PCBs from the Allen Mill in 1991-1993, thus adding substantial uncertainty to the model's estimates. Third, EPA failed to consider or incorporate the documented occurrence of PCB dechlorination or degradation within the sediments. Fourth, there appear to be errors in EPA's "correction" of the GE PCB data to be consistent with EPA data. We address each of these issues in turn.

Relationship Between Solids Transport Components and PCB Fate Components

The inaccuracies in the solids transport model have significant implications to the PCB model. They result in overestimation of the transfer of sediment PCBs to the water column and underestimation of the reduction of surface sediment PCBs by burial. As explained in

Section II.A, we believe that the EPA model underestimates the solids loading from tributaries and overstates the resuspension and deposition rates. This, in turn, results in excess movement of PCBs from the sediment to the water column by way of desorption through instantaneous equilibration between resuspended particulate PCB and water column dissolved PCBs. Based on available information and generally accepted theory, we believe that the Report's conclusion that sediments have a dominant influence on water column PCBs is incorrect.

EPA can take the following actions to improve the accuracy of its PCB fate model:

- Use the 1994 TSS study to refine the solids loading estimates for all of the tributaries. Particular attention should be paid to the solids yields from Snook Kill and Moses Kill.
- Eliminate resuspension at low flows unless there is conclusive evidence that this phenomenon occurs in the Upper Hudson River.
- Incorporate the concept of bed armoring into the description of high flow resuspension. This is best accomplished by using the theory incorporated in the scour model.
- Calculate sedimentation as part of the solids mass balance.
- Incorporate the variation in solids load composition and deposition velocity with river flow.
- Calibrate and validate the sediment transport model against data for multiple floods.
- Validate the balance between solids loading and resuspension by comparing computed and observed water column PCBs during floods.

Initial Sediment Conditions

EPA's model relies entirely on 1991 sediment sampling data to establish the initial composition and concentration of PCBs in sediments in 1993. The release of substantial quantities of fresh PCBs and sediment to the River between the fall of 1991 and the spring of 1993, combined with alteration of these fresh PCBs, undoubtedly resulted in a significant change in the composition and concentration of surface sediments in the TIP and perhaps elsewhere in the Upper River. GE estimates that the collapse of the Allen Mill in 1991 resulted in the release of substantial quantities of PCB-containing sediment from scouring of sediments in the Mill's tailrace tunnel. Since this occurred during a period of low flow in the Hudson River, it is likely that a significant portion of the sediment-bound PCB was deposited upstream of the Thompson Island Dam ("TID"). As a result, relying on data that do not reflect this significant event creates substantial uncertainty in the calibration of EPA's model. We recommend that the starting date for initial sediment conditions in the model calibration be at a point in time for which sediment data exist, such as 1991.

The impact of the changed sediment conditions may be evident in PCB concentrations in fish in the TIP. Comparisons of the changes in PCB content in brown bullhead, largemouth bass, and pumpkinseed in the TIP and at Stillwater following the 1991 and 1992 PCB releases shows a greater increase in the TIP, as shown in Figure 1. Given that water column concentrations were similar at the two locations, the impact in the TIP would only be greater if exposure concentrations in the sediments increased to a greater extent in the TIP than at Stillwater. The higher sediment concentrations might be reflected in the increased PCB levels in brown bullhead and largemouth bass (both of which derive some of their PCBs from sediments) caught in the TIP compared to those caught near Stillwater; and the lack of any discernable difference in the PCB levels in pumpkinseed (which derives most of its PCBs from the water column) caught at these two locations. This suggests an increase in surface sediment concentrations of PCBs in the TIP following the discharges from the Allen Mill.

Analytical Issues

An important issue identified in the Report is an apparent discrepancy between the GE PCB data and the EPA data (U.S. EPA, 1996b; pg. 4-13). EPA believes that the GE data set significantly underestimates the amount of congeners BZ4 and BZ10. The GE methodology, which was based upon the EPA analytical method used in the Green Bay Mass Balance study, utilizes a DB-1 capillary column. With this column, PCB congeners BZ4 and BZ10 coelute in peak 5. The method used by EPA for the Hudson River, in contrast, is able to distinguish these peaks.

Knowledge of PCB congener composition is useful in evaluating the sources of PCBs that are responsible for the measured PCB load in the TIP water column because the various PCB sources may have different congener compositions. Studies have shown that the sediment PCBs have been subjected to extensive anaerobic dechlorination (Abramowicz, 1991; Brown, et al., 1987) and that the sediment PCBs are enriched in congeners with fewer chlorine atoms than the PCBs entering the pool at Rogers Island, which appear to be mainly undechlorinated Aroclor 1242.

Additionally, recent work (Fish and Principe, 1994) demonstrates that dechlorination may occur on relatively short time scales (6-12 months) and in surface sediments, not just deeply buried sediments. Congener BZ4 is produced during this process and high levels have been found in sediments. Because the EPA-developed analytical technique used by GE underestimates the amount of this congener present in the water column, the PCB load in the TIP does not appear as dechlorinated in reports of the GE data as it does in EPA's own data. In fact, the composition of PCBs in the TIP water in the GE data closely resembles unaltered Aroclor 1242 that has partitioned from sediment particles to the water column, whereas EPA's data suggest that the PCBs in the TIP water derive from dechlorinated PCBs.

GE is working to understand why the EPA Green Bay method underestimates these congeners. The 1994 Cook memorandum EPA provided to GE describes the differences in the EPA and GE method for many Aroclor standards. Based on our initial review, it appears that the Green Bay method used by GE was based on flawed assumptions concerning the amounts of certain congeners in the tested standards. Recent work by GE provides more accurate assessments of which congeners are present in each Aroclor standard. This information should allow a correction to be made to the existing GE data, and preliminary recalculations of congener levels in the various standards compared to those reported in the 1994 Cook memorandum are in much better agreement. When this analysis is completed, we will document our findings and any corrections applied to the data.

It is unfortunate that EPA did not communicate to GE its knowledge of this important discrepancy in a more timely way. For the last two years GE has continued to generate data using the Green Bay method under agreement with EPA as part of the Remnant Deposits Monitoring Program. If notified earlier, we could have altered our analytical method to be consistent with that used by EPA, thus eliminating, at least in part, the need to "correct" for different analytical methods.

Dechlorination/Biodegradation Issues

Work performed by GE (Abramowicz, 1991; Brown et al, 1987) and others (Quenson, et al., 1990) clearly demonstrates that naturally occurring microorganisms in the sediments of the Upper Hudson River have extensively altered PCBs in the sediment. Biodegradation in the anaerobic sediments has resulted in the extensive loss of chlorine, a result confirmed by the EPA high resolution coring data (U.S. EPA, 1995). This chlorine loss causes a reduced bioaccumulation potential compared to that of unaltered Aroclor 1242 and also a potential reduction in PCB toxicity. Additionally, researchers have found that in aerobic sediment, aerobic bacteria destroy the more lightly chlorinated PCBs. This process has generally been found to occur in aerobic surface sediments, but some researchers have also detected metabolites of this process in subsurface sediments (anaerobic) of the Upper Hudson River.

EPA's models neither incorporate nor acknowledge these potentially important fate processes. To use this information, one needs an estimate of the rates for these processes. Recent laboratory work conducted by Ken Fish of GE (Fish, 1996) demonstrates that the introduction of unaltered Aroclor 1242 in Hudson River sediments under expected River conditions can result in extensive dechlorination and degradation in less than one year. Because EPA will presumably use its model to project PCB levels decades into the future, these processes should significantly impact PCB levels in surface sediments, even if the rates of dechlorination and degradation seen in the laboratory are faster than those that occur in the River. As a result, EPA's models should account for dechlorination and degradation of PCBs.

These processes may also be important in understanding the fate of PCBs entering the river near Hudson Falls and their relationship to the PCB imbalance across the TIP. One hypothesis for the high PCB water column loading in the TIP (see Section II.C) is that PCBs may be entering the pool undetected and then settling into the surface sediments. According to EPA water data, the PCB load in the TIP appears to be derived from dechlorinated sediments. It may be that newly deposited PCBs are undergoing rapid alteration as shown by Fish's laboratory studies.

Lastly, one of the key objectives of the reassessment is to determine what levels of PCBs in fish are acceptable and when they will be achieved. Dechlorination affects which congeners are available to consumers of fish and the concentration or mass of those congeners. EPA's recently released PCB Toxicity Reassessment (U.S. EPA, 1996a) recognizes a reduction in toxicity with lower chlorination levels. Also, the PCB congeners of primary concern in the Hudson River, BZ77 and BZ126 (coplanar congeners), which are thought to exhibit dioxin-like toxicity, have been found to be dechlorinated in the Upper Hudson River. Thus, dechlorination and biodegradation affect both the degree of exposure and the chemical to which people are exposed. Because these processes have been demonstrated to be occurring in the Upper Hudson, EPA should attempt to incorporate them into its modeling effort.

C. PCB Mass Imbalance in the Thompson Island Pool

As we pointed out in the Introduction, one of the valuable aspects of modeling is the identification of areas requiring further data collection or refinement of judgment. Balancing the PCB mass across the TIP is such a case. It is apparent that EPA has been unable to achieve a PCB mass balance across the TIP without resort to mechanisms that can be hypothesized but not factually demonstrated. GE has met the same obstacle in its modeling effort (HydroQual, 1995b). In EPA's model, PCBs are introduced into the TIP water column from four sources: 1) PCBs are diffused from sediment-pore water; 2) PCBs desorb from sediments that are resuspended; 3) PCBs enter the pool from upstream; and 4) pore water containing PCBs is driven into the water column by groundwater discharge. Diffusion from pore water is not in dispute. GE questions, to one degree or another, the values that EPA has used for other PCB transport mechanisms, and as discussed in Section II.A, we believe that the resuspension rate EPA used is too high. While we are in substantial agreement with EPA on the values used for upstream loadings, one must question whether those measurements have been able to capture the total loading source(s) because GE's upstream monitoring station may not be detecting discharges of dense oil. Finally, although we agree with EPA that groundwater discharge is a plausible hypothesis, the Agency must recognize both that it is only one of several hypotheses and that it has not been verified by field data. Further factual development and data collection is necessary before one can select the most likely hypothesis with confidence.

Consequently, GE is undertaking investigations to test all reasonable hypotheses for the PCB mass imbalance in the TIP. The PCB load in the TIP dominates PCBs in the water column downstream of the TIP. Knowledge of the source of the PCB load in the TIP is thus essential to determining whether and how the PCB load can be controlled. Regardless of GE's success in testing the hypotheses, EPA must be able to select a factually supported hypothesis. Otherwise EPA will lack a sound factual basis for its remedial decision, and any selected course of action will be arbitrary, with a very real probability that it will not have its intended consequences.

The hypotheses that must be tested in order to determine the cause of the mass imbalance of PCBs in the TIP include:

1. ***The mass and concentration of PCBs entering the TIP are markedly greater than the mass and concentration measured at the upstream Rogers Island monitoring station.*** This hypothesis - that PCBs escape detection at Rogers Island - is plausible because the known releases of PCB oil from the Hudson Falls plant area are denser than water, and the current monitoring program was not designed to detect or quantify dense oil phase PCBs. To the extent that PCB oil escapes detection at Rogers Island, either because it travels as part of an

unquantified bed load or as undetected pulse loadings, the present monitoring would underestimate PCB transport past Rogers Island. GE has conducted a number of monitoring studies this fall to address the issue of the representativeness of the current monitoring program. For these and the other hypothesis testing activity described in this section, GE will share the data and its analysis with EPA as the results become available.

2. ***The mass and concentration of PCBs passing the TID are markedly less than the mass and concentration measured at the TID monitoring station.*** Since we do not understand the mechanism by which excess PCBs enter the TIP, we can not be sure that the PCB monitoring conducted from the single point at the TID accurately represents PCB transport over the dam. Monitoring studies conducted this fall, including a longitudinal transect study following a single mass of water through the TIP, and water column monitoring conducted across the river near the TID, should provide insights into the representativeness of the TID monitoring station.

3. ***Groundwater inflow within the TIP is causing substantial release of PCBs from the buried sediments into the water column in the TIP.*** This hypothesis appears plausible because it can account for a portion of the excess PCB loading observed across the pool. The hypothesis has several weaknesses, however. First, as tested in the EPA model calibration, ground water advection is a spatially limited mechanism; it is invoked only in the TIP. Given the similarities between the TIP and downstream reaches, if groundwater were important to PCB releases in the TIP, one would expect it to contribute as well to PCB transport

in downstream reaches. Sediment diffusive flux alone, however, can account for PCB loading observed downstream of the TIP.

Second, the groundwater flux hypothesis cannot account for the temporal variability in the excess PCB loading from the TIP. The excess loading only appeared after the substantial discharges from the Allen Mill between 1991 and 1993. If groundwater advective flux is a significant contributor to PCB loadings in the TIP, then water column monitoring conducted prior to the event should contain some evidence of its existence. GE plans to evaluate the groundwater flux hypothesis by evaluating the groundwater system near the TIP and possibly deploying groundwater seepage meters within the TIP sediments.

4. ***There are markedly greater PCB concentrations in the surface sediments of the TIP (resulting from the 1991-1993 Allen Mill discharges) than reflected in the surface sediment data used in the model.*** This hypothesis is plausible as it accounts for the coincidence in timing with the Allen Mill discharges. Two of the EPA high resolution cores collected from the TIP in 1992 (after the initial Allen Mill discharges) show an increase in PCB concentrations near the sediment-water interface. These surficial sediment layers reflect recent PCB deposits. As stated in Section II.B, comparison of PCB content in brown bullhead, largemouth bass, and pumpkinseed in the TIP and at Stillwater before and after the 1991-93 releases shows a greater increase in the TIP than at Stillwater (see Figure 1). The brown bullhead and largemouth bass derive more of their diet from the sediment than does the pumpkinseed. This suggests an increase in surface sediment concentrations of PCBs in the TIP following the discharges from the Allen Mill.

Higher surface sediment concentrations could increase the driving force for diffusive transport from the sediment to the water column and may account for some of the excess PCB observed in the River. This mechanism alone, however, cannot account for all of the excess PCB because the PCB congener pattern of excess loading reflects some degree of dechlorination. Therefore, a post-depositional process of PCB dechlorination is required to produce the PCB congener pattern of the loading. Although recently conducted laboratory experiments (Fish, 1996) indicate that dechlorination can occur at a rate sufficient to contribute to the excess loading as described above, extrapolation of these results to the field is not yet complete. These studies suggest, however, that the combined process of deposition of PCBs into surficial sediments followed by dechlorination is a possible cause for the excess PCB loading from the TIP.

5. ***A substantial mass of PCBs enters the TIP between Rogers Island and the TID from sources outside the Pool, such as dredge spoil sites.*** While this hypothesis is possible, it is unlikely because there is no physical explanation why the external load from these sources would be correlated in time with the discharges from the Allen Mill. The spatial pattern

of PCB loading within the pool as discerned from the longitudinal transect studies described above should provide further insight into whether the dredge spoil sites might contribute to the TIP PCB loading.

6. *Resuspension of surface sediments introduces a substantial mass of PCB into the water column of the TIP.* The EPA model invokes sediment resuspension during low flow periods to account for a portion of the excess PCB loading observed in the TIP. While this hypothesis may account for the temporal correspondence between the Allen Mill discharges and the excess PCBs emanating from the pool (the resuspended surface sediments may contain elevated PCBs originating from the Mill), it is counter to the generally accepted understanding of sediment transport processes. Under current theory and experience, surface sediments are not appreciably resuspended until river flow velocities produce a critical shear stress at the sediment-water interface. This critical shear stress occurs at river flow velocities substantially higher than those that occurred during the periods of excess loading. The marginal increase in TSS observed during the excess PCB loading periods can be accounted for by tributary loadings from the Snook Kill and Moses Kill. Indeed, the longitudinal transect studies conducted this fall substantiate this conclusion because TSS did not increase in the TIP until downstream of these tributaries.

D. <u>Long-Term PCB Mass Balance</u>

The current EPA model does not calibrate to the existing data for 1993, matching neither the low flow PCB data nor the PCB load at the TID. We have discussed the potential reasons for this in prior sections. Indeed, the limited calibration period is insufficient to test the model's ability to represent the long-term fate of sediment PCBs, in particular the impacts of resuspension, sedimentation, dechlorination and biodegradation. Based on GE's own modeling and data evaluations, this problem will become more significant when EPA compares the model results with the vast array of historic PCB data in fish, water, and sediment (EPA refers to this as "hindcasting").

Two critical tests of the match between the historic data and the results of the current EPA model are likely to show unacceptable incongruity between the data and the model. The first test of the model is its congruence with the amount of PCBs present in the water column at Schuylerville in the mid- to late-1980s. If the EPA model were used, incorporating EPA's assumed low flow resuspension and groundwater inflow to move PCB from the sediment into the water column, one would expect approximately 100 ppt of PCB in the water column at Schuylerville during low flow in the summer months. In fact, the average value measured by the U.S. Geological Survey in 1988 and 1989 is 30 ppt. This is close to the amount one would estimate from diffusion alone.

The second test of the EPA model is its congruence with the inventory of PCB mass in the sediments over time. If significant amounts of PCB were moved into the water column from the sediments, as the EPA model assumes, there should be a discernible change in the PCB reservoir in the sediments or the depth profile of PCBs in the sediment. Three large scale sediment sampling events were carried out in the Upper Hudson in 1977, 1984, and 1991 which can be used to estimate the mass of PCBs in the sediments of the TIP. EPA has estimated that the TIP sediments contained about 32,000 pounds of PCBs in 1984 (U.S. EPA, 1996b, pg. 6-2). The EPA model estimates that 800 pounds of PCBs are lost from the sediments into the water column over the 270 days in 1993. If the same rate of loss were projected into the past (presumably an underestimate because PCB levels in the sediment would have been higher earlier), the total mass of PCB mass lost from 1984 to 1991 would be 8,000 pounds, or approximately 25% of the total inventory. This is inconsistent with the historic sediment data which show little change in PCB inventory over fifteen years.

Another way to compare the model results to the historic levels of PCBs in the sediment is to compare PCB depth profiles over time. Unfortunately, the current EPA model has decoupled sediment transport and net sedimentation rates (see Section II.A), making such a comparison difficult. EPA should link the sedimentation rate and the solids mass balance portions of the model. If the PCBs were being flushed out of the sediment, as the EPA model predicts, then the loss of bioavailable PCBs due to long term burial would be less significant than if less interaction between the sediment water column were occurring. Comparing the PCB profiles in the sediment over time to the model predictions should provide a check on the model assumptions.

Long term burial as the dominant mechanism for loss of bioavailable PCBs is consistent with the available data reviewed to date. As an illustration, consider the vertical profiles of PCB concentrations in TIP sediment shown on Figure 2. Each panel shows measured sediment PCB concentrations, averaged over selected depth intervals, for the years 1977, 1984 and 1991. In the panel on the left, the PCB concentrations for each depth interval are plotted against the depth of the slice. The surface to 5 cm slice is plotted at a depth of 5 cm, corresponding to the depth at which material would be buried below a mixed "active layer" 5 cm deep. The other concentrations are plotted at the depth below the sediment-water interface of the mid-point of the associated sediment core slice. When plotted in this manner, the only obvious pattern in the data is that the surface concentrations decreased from 1977 to 1984 to 1991, and the deeper concentrations (50 to 70 cm) are relatively higher than the surface sediment concentrations.

The middle and right panels of Figure 2 show these same sediment PCB profiles, but with the measured profiles modified in the following manner. First, the surficial (0-5 cm) concentrations are reduced by 20%, corresponding to an upper bound limit to the potential degradation of PCBs associated with anaerobic dechlorination processes. (This decrease is only applied to the mixed surface layer, since this is the only layer likely to have relatively recently deposited, undechlorinated PCBs). Second, the 1977 and the 1984 PCB profiles are shifted downward to correspond to the depth of burial that would occur from the time of sampling (1977 or 1984) to 1991. This vertical translation corresponds to a long term average net sedimentation rate of 0.5 cm/year on the middle panel and 1.0 cm/year on the right hand panel. With these modifications applied to the data, the blurred image described by the untranslated profiles on the left panel comes into focus and a relatively distinct, unified profile emerges. This is consistent with the conclusion that burial has simply moved the PCB profiles measured in 1977 and 1984 down in the sediment, modified by some degree of dechlorination, possibly in combination with other loss processes, in the surface layer. The actual burial rate is difficult to discern with precision, but this analysis suggests that it is on the order of 0.5 to 1 cm/year. Since the PCB data are reach average results, this burial rate is indicative of a reach average long term net sedimentation rate. These data do not support EPA's hypothesis that PCBs are being "flushed" from the sediment at the high rate calculated by the EPA model.

*   *   *

Based on GE's evaluation of the EPA model, it is clear that the model will need significant revisions to calibrate properly to the historic data. The current EPA model greatly overestimates the amount of PCBs contributed to the water column by the old sediments. If left unchanged, future projections will show exaggerated benefits from sediment remediation projects if the projection focuses only on the present loss rate from buried sediments. If the predicted loss rate were continued into the future, the sediments would be largely depleted of PCBs in the near future, which implies that remediation is unlikely to shorten significantly the period required to achieve acceptable risk levels.

To complete the modeling effort and to answer the key questions for the Reassessment, the source of the TIP load imbalance must be understood. The Reassessment cannot be completed in a defensible way until this is done. This will be a major focus of GE's efforts in 1997, and GE looks forward to working closely with EPA to unravel this important technical issue.

III. BIOACCUMULATION MODELS

EPA is developing three bioaccumulation models to predict PCB levels in fish: The Bivariate Statistical Model ("BSM"), Probabilistic Food Chain Model ("PFCM"), and the Gobas Model ("GM"). Each has its strengths and weaknesses. The BSM and PFCM are essentially steady-state statistically-derived models that rely on examinations of historic PCB levels in sediment, water column and biota to ascertain the relationship among these natural compartments. Because they ignore the short and long term variability in the relationships among PCB levels in water column, sediment, and fish and do not attempt to discern the mechanisms by which fish bioaccumulate PCBs, these models will have limited utility for predicting PCB levels in fish in the future. The GM, on the other hand, is a time-variable, mechanistic food web model, which explicitly incorporates variability in exposure, uptake and depuration of PCBs and which, because it reflects real world bioenergetic and toxicokinetic mechanisms, provides a useful and easily checked predictive tool. For these reasons, GE urges EPA to develop and use a time-variable mechanistic food web model, such as the GM, using the statistical relationships developed through the BSM and PFCM, as well as the performance of the model in other systems, as external checks on its dynamics and output.

A. The BSM and PFCM Models

Structure of the Models

The BSM and PFCM are models that attempt to derive quantitative relationships between PCB levels in sediment, water, and fish through statistical analysis of Hudson River data. The BSM examines these data using multiple regression analysis to estimate average PCB levels in fish from PCB concentrations in sediment and water. The PFCM is similar, except that it involves characterizing the historic data and food web transfers within the River to estimate trophic transfer factors ("TTFs") between each link. Using Monte Carlo techniques, the model is intended to be used to estimate the mean and variation in PCB levels in top predators, given average exposure levels in sediment and water. Regardless, like the BSM, it is a statistically-based model.

The statistical, steady-state nature of these models limit their utility as predictive tools. Moreover, the inconsistency in their use of sediment PCB data undermines their validity. First, both models assume that PCB levels in the biota are near steady-state with regard to levels in the sediment and water. PCB levels in biota in the Upper Hudson River, however, have exhibited relatively slow long-term declines, as well as significant short-term changes. Lipid content of some species has also changed dramatically over time, exhibiting both long-term trends and year-to-year variation. Because PCBs tend to accumulate in lipid, the variability in lipid content results in changes in excretion rates, which, in turn, cause variation in PCB body burden on the scale of one to a few years. Ignoring these temporal changes in the system lends significant uncertainty to the validity of these models.

Second, both models ignore the causal mechanisms by which fish bioaccumulate PCBs. The primary advantage of the regression approach used in these models is that it is relatively simple. Only the site-specific data are required; no ancillary information on bioaccumulation processes is needed. This simplicity is also their primary disadvantage. While the PFCM, for example, explicitly incorporates variability in PCB levels in sediment, water, and biota to derive the TTFs, the model does not allow one to discern the cause for that variability. By failing to incorporate available information about the biological mechanisms for the variation in contaminant levels in fish, such as growth rate, size, lipid content, feeding behavior, and exposure levels, these regression models do not allow one to assess, for example, how PCB body burdens will change over time as the relative importance of sediment and water column PCB levels change.

Third, another flaw in the PFCM is that it requires having the answer to solve the problem. The observed variability in a fish population is input into the model in the form of the variability in the TTF, and the model then calculates the variability in the fish population. The model is circular.

Fourth, the model is improperly structured. It attempts to calculate variability (population variance) from uncertainty (standard errors of the mean TTFs). These metrics are incompatible, and the model results have no physical meaning.

Fifth, these models, as applied by EPA, incorrectly assume that surface sediment concentrations of PCBs have remained constant over time. In addition, the models rely on different and inconsistent sediment data: both models rely on a single year's sediment data - for the BSM, the 1991 GE data; for the PFCM, the 1993 EPA data. The inconsistency in data raises questions about the comparability of results from the two models. The assumption that temporal changes in sediment PCB concentration will not affect PCB levels in fish is flawed in light of the generally accepted understanding that surface sediment PCBs can contribute significantly to PCB levels in certain fish species. (The assumption is odd in a reassessment focused on whether or how remediation of sediments might reduce PCB concentrations in fish). Yet, EPA used a single set of sediment data to compare to all the historical data on PCB levels in water column and fish, thus compromising the validity of the statistical analysis. The appropriate approach is to couple the bioaccumulation modeling to the water and sediment exposure concentrations computed by the PCB fate model.

For the PFCM, EPA estimated BSAF values for benthic invertebrates using a limited number of cores and data from several species of invertebrates. Each species of invertebrate may feed in a different manner, leading to differences in exposure concentration. The distribution of invertebrates sampled may differ from the distribution of invertebrates actually consumed by forage fish. In addition, EPA estimates the trophic transfer from water column particulates to water column invertebrates using the historical multiplate and caddisfly data. EPA assumed that the fine fraction of material on the multiplates represents water column particulates, but this material may not represent particulates that caddisflies foraging just above the sediment bed consume. Finally, EPA failed to consider the uncertainty associated with its assumption that the caddisflies are representative of the water column invertebrates in the diet of the forage fish.

Validation of the Models

EPA has not adequately validated the models:

(1) The Report presents temporal trends for pumpkinseed, brown bullhead and largemouth bass at river mile 175 but not for the TIP, where the BSM and data do not match as well.

(2) The Report compares BAF values estimated by the BSM with values calculated using the GM at other sites. While it is appropriate to compare values with other sites, EPA should make these comparisons against data from field populations of similar species in similar ecological settings, rather than values calculated using another model for another system. Moreover, because both the sediments and the water column are important sources of PCBs to the fish, EPA should compare both BAF and BSAF values with other systems, not just the BAF.

(3) The analyses used by EPA to test the BSM demonstrate that it will not be useful for predicting fish PCB levels. The Report gives values of the coefficients of determination of the regressions (r^2). The r^2 value is a measure of the proportion of variation in the data that is accounted for by the regression. In addition, the Report presents scatter plots of

observed versus predicted PCB levels. The Report does not present any other statistical analyses to evaluate goodness of fit. In addition, the scatter plots show problems with the predictive ability of the models:

- The slopes of these values are often less than one, indicating that there is a bias in their predictions.
- Predicted values are often higher than observed at low concentrations. (See Figures 9-8 to 9-13). This high bias will be critical when making predictions of future PCB levels in fish, when exposure levels should be reduced. Thus, the models' projections will be biased high.
- The pattern of observed versus predicted values differs among reaches. For example, within the TIP, predicted values vary little temporally while observed values have considerable variability. This suggests that the models do not provide accurate predictions of PCB levels within each pool.

B. The Gobas Model

A time-variable bioenergetics-based food web model such as the GM overcomes the major failings of the BSM and PFCM. The GM can represent key time-dependent features of the historical data: short term exposure changes and variations in lipid content and changes in sediment and water column concentrations over time. This results in a calibration that more accurately represents the relationships among PCBs in water, sediment and biota. Also, the validity of the model's coefficients can be evaluated because they have biological meaning. Finally, because the model is mechanistic, causes for differences between model and data can be explored, leading to further field measurements or experimental work to improve the model parameterization and predictive capability.

In the Report, EPA suggests that poor knowledge of many of the important model parameters hampers the GM approach (U.S. EPA, 1996b; pg.8-13). Actually a significant amount of information exists to provide adequate constraints on the model. All of the informational requirements for development of the GM can be met. Food web structure and fish natural history have been evaluated in the PFCM. The uptake and depuration rates of PCBs can be estimated from field and laboratory data and other modeling studies. Uncertainty and variability associated with these parameters can be used to generate predicted uncertainty and variability in fish PCBs. As a result, lack of data is not a valid reason not to develop the GM.

C. Recommended Approach

We recommend that EPA use a time-variable bioenergetics-based food web model, such as the GM, to estimate mean PCB levels, and that this model be coupled to the PCB fate and transport model to integrate the predictions of exposure and bioaccumulation. GE is developing such a model and believes that it would provide a solid basis for work in this area. We recommend that this model be further developed in a cooperative effort that takes advantage of the knowledge and expertise of both GE and EPA. Further, we recommend that EPA use the observed coefficients of variation in conjunction with the calculated mean PCB levels to describe the distribution of PCB levels for use in the risk assessment.

IV. DEPTH OF SCOUR MODEL

GE is in basic agreement with the approach EPA used to model the 100 year flood. The model is consistent in its characterization of the resuspension properties of cohesive sediments and appropriately incorporates field data from the TIP. Nevertheless, EPA should correct several errors in the model.

First, the EPA model uses an improper method to calculate bottom shear stress distribution in the TIP: outputting predicted current velocities from the RMA-2V hydrodynamic model and using an external formula (Equation 5-3) to calculate shear stresses. This approach is inconsistent because Equation 5-3 predicts different bottom shear stresses than does from RMA-2V. The correct approach is to output the bottom shear stresses calculated by RMA-2V and use those values to calculate cohesive sediment resuspension.

Second, EPA did not properly use the Lick equation for calculating resuspension potential. The Lick equation calculates resuspension potential (ϵ), which is expressed as eroded sediment mass per unit area; i.e., grams/cm^2. Converting predicted resuspension potential at a particular location to a scour depth (Z_{scour}) requires application of Equation 3-7; i.e., $Z_{scour} = (\epsilon) / C_{bulk}$. In this equation, C_{bulk} is the *dry* bulk density (grams/cm^3), where

$$C_{bulk,dry} = (1 - P)\,\rho_{sed}$$

and P = porosity and ρ_{sed} = sediment particle density ($\approx$ 2.65 grams/cm^3). The dry bulk density represents the dry sediment mass per unit bed volume and is also referred to as the bed solids concentration. Examination of EPA bulk density and solids data suggests that the EPA database lists $C_{bulk,\,wet}$, not dry bulk density. It is inappropriate to use wet bulk density ($C_{bulk,wet}$) to calculate Z_{scour}:

$$C_{bulk,wet} = P\,\rho_w + (1 - P)\,\rho_{sed}$$

where ρ_w = water density ($\approx$ 1 gram/cm^3). The wet bulk density is the mass of water and sediment per unit bed volume. If EPA did use wet bulk density, it should convert those wet bulk density values to dry bulk density as follows:

$$C_{bulk,dry} = \rho_{sed} (C_{bulk,wet} - \rho_w)/(\rho_{sed} - \rho_w)$$

Third, as previously discussed, an inconsistency exists between the treatment of cohesive sediment resuspension in EPA's solids transport model and in the depth of scour model. The depth of scour model uses a formulation, the Lick equation, that accounts for bed armoring effects and also utilizes Upper Hudson River resuspension data to determine site-specific parameter values. Eliminating the inconsistency between the two models and incorporating the Lick equation into the solids transport model is necessary to achieve credible solids transport simulations using EPA's solids transport model.

Finally, a major uncertainty remains for the depth of scour model: how will EPA simulate non-cohesive resuspension? Research on suspended load transport of non-cohesive sediments has a long history, and researchers have proposed a wide variety of formulas and methods. The various formulas have been tested on a number of different data sets, from laboratory and field studies, and found to produce accurate results under a wide range of conditions. Thus, EPA must carefully screen these formulations to find one that is appropriate for the TIP. GE requests that it be informed of EPA's choice in sufficient time to comment before EPA develops its final product.

One formulation that has produced reliable results is the van Rijn model for suspended load transport of sands (van Rijn, 1984). This model would be appropriate for the TIP with some modifications. The van Rijn model was developed for an ungraded bed; i.e., relatively uniform-size sand particles. The non-cohesive bed in the TIP consists of a wide range of particle sizes, with a significant fraction of coarse sand and gravel. Under these conditions, EPA needs to consider the effect of bed armoring due to heterogeneous bed composition and modify the van Rijn equations appropriately. Extensive research on non-cohesive bed armoring has resulted in the development of credible formulations which have been successfully applied in modeling studies on other rivers (Ziegler and Nisbet, 1994).

Realistically simulating non-cohesive suspended load transport in the TIP depends not only on the model formulations, but also on specification of bed property parameters and the flood hydrograph. EPA must determine the distribution of non-cohesive bed parameters (e.g., grain size distribution) in the TIP with extreme care because model results are very sensitive to input parameters. EPA also needs to include the effect of the flood hydrograph on non-cohesive erosion in the 100 year flood simulation. The steady-state flow assumption presently used is valid for approximating cohesive resuspension. Non-cohesive erosion, even with bed armoring, is rate-dependent, however, and total scour in the non-cohesive bed will depend on the flood hydrograph; a steady-state assumption will not yield credible results.

EPA will need to calibrate the depth of scour model after adding the non-cohesive component because of the uncertainty in the non-cohesive bed property parameters. EPA collected an excellent TSS data set during April 1994 and should use it to demonstrate that the non-cohesive component of the depth of scour model is functioning with reasonable accuracy. Without some form of model calibration, predictions of non-cohesive sediment erosion during high flow events will be very uncertain and can not be used with confidence in evaluating the effects of the 100 year flood.

V. PREDICTIVE POWER OF THE MODEL

The purpose of developing models in the reassessment is to understand the complex relationships of the natural elements operating in the Upper Hudson River and on that basis to predict the effect of possible future action and no action. EPA has calibrated its fate and transport model to a temporally limited data set collected between January 1 and September 30, 1993. There is a very extensive array of data for some parameters for ten years or more prior to 1993 and for the period since September 30, 1993. This presents a crucial and significant test of the predictive power of the EPA model. If the EPA model is able to provide a close fit to the data points before and after 1993, the arguments for its use as a predictive tool will be very powerful. If it is not possible to validate the model by a close fit to the data, its lack of usefulness for predictive purposes will be apparent. If this is the case, it should follow that further significant analysis, data collection, and model development will be necessary before it can be used by decision makers in the reassessment.

In determining whether the model meets an acceptable standard for predictive use, the model's ability to match the data closely in the following instances will be the acid test of success:

1. To validate the components of the solids balance, EPA should compare model results with data on:

   a. Spatial patterns of TSS during low flow periods, which will evaluate the balance between low flow solids loading and deposition;

   b. Temporal and spatial patterns of TSS and water column PCBs during flood events, which will evaluate the balance between high flow solids and resuspension; and

   c. Annual average solids loading passing Schuylerville, Stillwater and Waterford, which will evaluate the balance between solids loading and sedimentation.

2. To validate the flux of PCBs from pore water and PCB loss by volatilization, EPA should compare model results with data on:

   a. Spatial patterns of water column PCBs during low flow periods; and

   b. Spatial changes in water column PCB composition (based on the five congeners modeled).

3. To validate the mechanisms by which bioavailable PCBs are lost from the sediments, particularly the balance between losses to water column (diffusion and resuspension) and losses by burial, EPA should compare model results with data on:

   a. Long-term changes in surface sediment PCB levels;

   b. Long-term changes in the vertical profiles of PCBs in sediments; and

c. Long-term changes in PCB inventory in the sediments.

4. To provide an overall test of the model, EPA should compare model results with data on the annual average flux of PCBs passing Schuylerville, Stillwater and Waterford.

5. To test the model's ability to describe the impact of recent PCB releases from Hudson Falls, EPA should compare model results with data on the apparent increase in the PCB flux from Fort Edward to Thompson Island Dam/Schuylerville that occurred between the mid- to late-1980s and the 1990s.

6. Finally, to evaluate the food web structure and toxicokinetics of the bioaccumulation model, EPA should compare model results with data on:

a. Temporal changes in PCB concentrations in a predatory fish (largemouth bass) and in a forage fish (pumpkinseed) at the TIP and Stillwater over a 15-year period. In addition to overall fit between model and data, patterns in the quality of fit should be explored (e.g., differences among species, locations, time periods); and

b. Response of the fish to the short-term changes in water column PCB levels in the early 1990s, which will evaluate the relative contributions of water column and sediment PCBs and the uptake and loss ratio.

In assessing the capability of the model to match data, care must be taken to uncover any apparent biases. The current calibration exhibits several biases that are not discussed in the Report. For example, water column PCB concentrations are generally over-predicted at low flow and under-predicted at high flow. The over-prediction is likely due to the inclusion of resuspension at low flow. The cause of the under-prediction at high flow is uncertain. It may be a real bias, or simply a slight mistiming. EPA should examine this issue as part of its recalibration efforts. The model also underestimates the solids loading passing Stillwater and Waterford during the non-event period. For the calibration period, the model is low by about 5,000 MT at Stillwater (U.S. EPA 1996b; Figure 4-11) and 30,000 MT at Waterford (U.S. EPA 1996b; Figure 4-12). These differences between model and data suggest an underestimation of low flow tributary solids loading. The Report presents the hypothesis that construction activities at Lock 1 temporarily increased solids loading, but gives no data supporting this hypothesis. Given the importance of the solids balance to long-term predictions, EPA needs to examine the possibility of and reasons for model bias. Finally, as discussed in Section III, fish PCB concentrations are overestimated at low levels. As with the other biases, cause must be determined, and the bias eliminated before EPA uses the model as a predictive tool.

VI. LOWER HUDSON PCB TRANSPORT AND FATE MODEL

The cover letter to these comments addressed the question of what consideration of conditions in the Lower River is appropriate in a reassessment directed to what action, if any, should be taken with PCB-contaminated sediments in the Upper Hudson. As we noted, it is important to ensure that any remedial action in the Upper River has no adverse impact, or, at most, an acceptable adverse impact on the Lower River. It is not appropriate, however, to justify remedial action in the Upper River on the basis of benefits to the Lower River. If EPA is to consider benefits to the Lower River, it must examine remedial action in the Lower River, such as source control, to assure that a remedy designed to achieve Lower River benefits is cost-effective. If the Agency follows the course of seeking benefits for the Lower River, it must also identify Lower River dischargers as PRPs. Thus, assuming EPA maintains the present limited focus of the reassessment, it must limit the examination of impacts on the Lower River and its fish to assuring that a remedy in the Upper River will not have an unacceptable adverse impact on the Lower River.

With regard to the Thomann model, GE does not believe that it indicates that a remedy in the Upper River would adversely impact the Lower River and therefore does not object to its use for that purpose. From the point of view of technical accuracy and soundness in model development, there are a number of comments that could be made. We recognize, however, that Thomann and Farley are in the midst of a thorough review of the model and believe it appropriate to wait for the conclusion of that review to determine whether there are any disputed aspects of the model that are of relevance to use for the limited purposes appropriate for this reassessment. We believe that EPA should also wait for completion of the revision of the Thomann model before using it in this reassessment.

EPA should also consider other analyses in addressing whether a remedy in the Upper River would have an unacceptable adverse impact in the Lower River. In particular, Chilrud (1996) has completed a quite different sort of analysis of PCBs in striped bass in the Lower Hudson. EPA should review Chilrud's work in the same context in which it has examined Thomann's model.

Finally, the Report states that EPA intends to extrapolate from striped bass modeling results (derived from the Thomann model) to estimate impacts on the short-nose sturgeon (U.S. EPA 1996, p. 8-3). It is not clear how EPA would carry out this extrapolation, and GE requests the opportunity to comment on whatever method EPA may propose. We are unaware of any data showing PCB levels in short-nose sturgeon in the Hudson, or data or analyses relating Upper River sources to PCB body burdens in Hudson River short-nose sturgeon. We are unaware of any data or analyses showing adverse impacts in the short-nose sturgeon population as a result of PCB exposure and uptake. Finally, we are unaware of what sort of adverse impact as a result of what sort of PCB exposure is claimed to occur in the short-nose sturgeon population. In fact, recent reports suggest that the short-nose sturgeon is now present in such abundance in the Hudson that its continued status as an endangered species may soon come to an end. All of these relationships need to be explicated before any defensible relationship between PCB-contaminated sediments in the Upper River and adverse impacts on the short-nose sturgeon population can be propounded.

VII. CONCLUSIONS AND RECOMMENDATIONS

To determine what action, if any, is necessary to address the PCB levels in the sediments of the Upper Hudson River, EPA appropriately determined that it had to develop objective, quantitative tools to predict the future levels of PCBs in fish, water and sediment under various remedial scenarios, including no-action. EPA has made substantial progress in developing a physically- based mechanistic model that will allow it to make such predictions. This is a complex and resource intensive project, but a necessary one.

GE commends EPA for seeking input on the preliminary modeling effort before completing construction of its models or attempting to utilize its models to make predictions. Based on our review, we agree with much of EPA's approach, including:

1) The overall goals of the reassessment and the role of the model in meeting these goals;

2) The guiding principles for model development; and

3) The general criteria by which to judge the reliability of a model.

The current iteration of EPA's models, however, will not provide a reasonable representation of PCB fate in the Upper Hudson River and cannot be used to address the key reassessment objectives. EPA must make modifications to the structure and calibration of its models. Additionally, the model effort has highlighted gaps in data that add significant uncertainty to the models. These need to be addressed before EPA can complete its modeling effort.

The two primary short-comings of the models are: 1) the assumed interaction between PCBs in the sediment and the water column, and 2) lack of knowledge concerning the source of a large portion of the PCBs entering the water column within the TIP. The first problem is largely a result of only using data from a 270 day period in 1993 to calibrate the model. The current model configuration results in a significant movement of PCBs from the sediment to the water column that is not consistent with current knowledge of processes affecting PCBs or with the historical data. Recalibration of the model to the large historic database will provide further constraints in determining the long term interaction between the sediments and water column, and will show the impact of sediment burial as a PCB loss mechanism.

The second major problem is that EPA assumes that PCB loading to the water column in the TIP occurs by processes that either are not physically reasonable or are entirely speculative. The assumed high resuspension and deposition rates, particularly at low flows, are not supported by current sediment transport theory. This results in an unreasonably large amount of sediment bed/water column interaction and an exaggerated flux of PCBs from the sediments to the water. In addition, EPA makes an untested assumption that 30 cfs of groundwater moves through the sediments in the TIP forcing PCBs from the deeply buried PCBs into the water column.

EPA acknowledges that the source of the PCB load imbalance in the TIP is not known. This load imbalance is a significant portion of the PCB water column load in the Upper Hudson River, and the source of this load must be determined if predictions of future conditions are to have any validity.

Ultimately, the PCB levels in fish are of concern. EPA's work to date has focused on the statistical correlation between PCB levels in fish, water and sediment, but EPA's models do not describe the physical basis for this relationship. GE encourages EPA to develop a time-variable mechanistic food web model because of its far greater explanatory power and its improved utility as a predictive tool compared to the statistical correlations EPA has prepared so far.

Before EPA uses the Thomann model, it must clearly define the objectives of this modeling effect and await the revisions that Thomann and Farley are preparing.

Based on these concerns, GE recommends that EPA take the following actions to complete its modeling efforts:

1. Develop and test by data collection, if necessary, the range of hypotheses that might explain the TIP load imbalance;

2. Refine the solids loading estimates for all tributaries, particularly for the Snook and Moses Kills;

3. Eliminate low flow resuspension and incorporate the concept of bed armoring into high flow resuspension. Also, incorporate solids composition into depositional velocity estimates;

4. Calculate, do not arbitrarily specify, net sedimentation using the difference between resuspension and deposition in the models solids balance;

5. Recalibrate the model using the full historical data set and the revised processes specified above. Specifically utilize:

    - Historic water column PCB levels;
    - High flow TSS and PCB values for multiple events (floods);
    - 1994 TSS data for tributaries;
    - PCB levels in sediment (total inventory as well as depth profiles) from the 1977, 1984 and 1991 surveys;

6. Develop and calibrate a time-variable bioenergetics-based food web model for fish in the Upper Hudson River;

7. Test the model by comparison to known data points to assure that each of its central elements is able to replicate the natural system the model is designed to imitate.

8. Clearly define the use of the Lower River model, and if appropriate, apply the revised model being developed; and,

9. Before using the revised models for predictive purposes, reissue the calibration report for additional comments.

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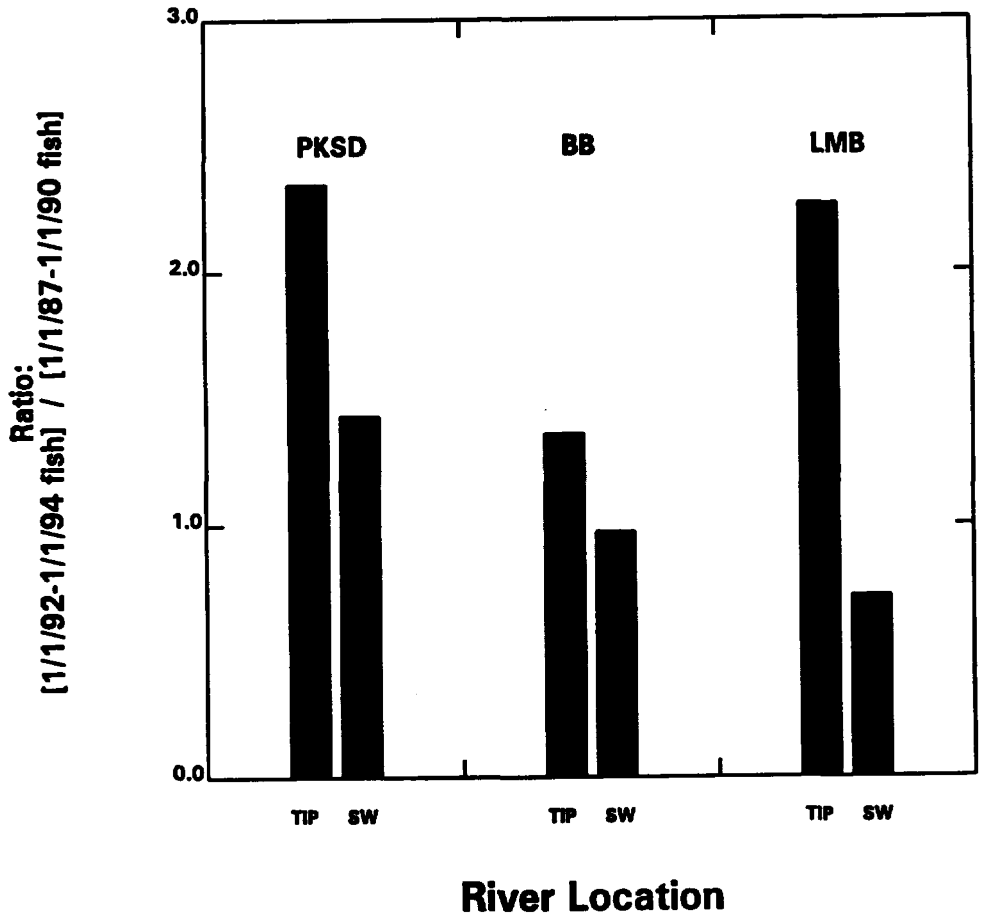

Figure 1. Ratio of Post-Release to Pre-Release Fish PCB Concentrations for Pumpkinseed (PKSD), Brown Bullhead (BB), and Largemouth Bass (LMB) in Thompson Island Pool (TIP) and Stillwater Pool (SW)

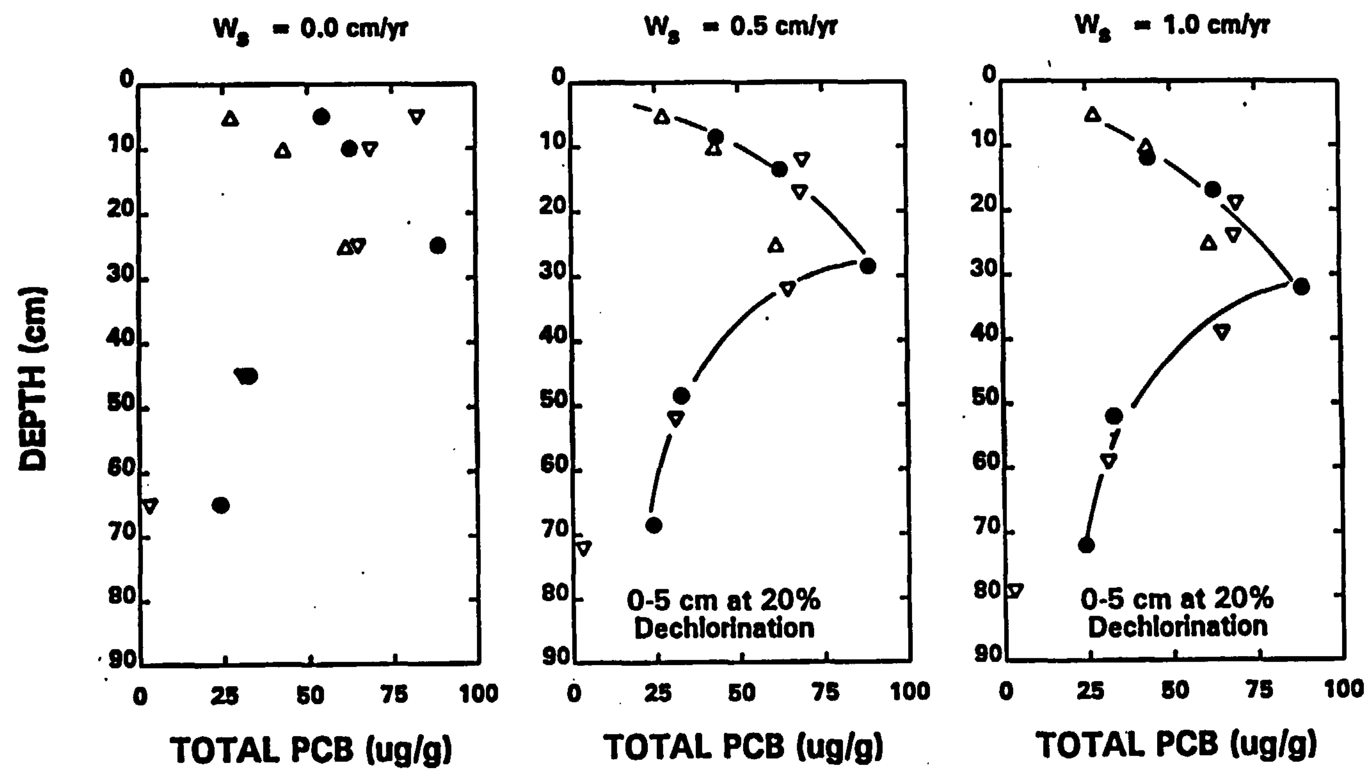

Figure 2. TIP Sediment PCB Profile (left) with Projected 1991 Profiles with Sedimentation and Dechlorination Mechanisms (center & right).

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